

## CHAPTER 4

# DESIGN AND MANAGEMENT OF RESERVOIRS

## 4.1 INTRODUCTION

### 4.1.1 Structure of the chapter

The design and construction of manmade reservoirs has some important adverse environmental and social impacts including loss of useful land, relocation of population, damage to historical values, disturbance of ecological systems, reduction in river self-purification capacity, sedimentation and increased risk of water-borne diseases. Can a manmade reservoir be sustainable? This chapter concentrates on reservoir design and management issues as they relate to the notion of sustainability. The objective is not to provide ready-made solutions for sustainable reservoir design and management, but to present some of the ideas that are developed to incorporate principles of sustainability in reservoir analysis.

After some definitions and an overview of reservoir analysis problems, reservoir purposes and tools for reservoir analyses, the chapter is organized into three sections. The importance of the hydrological input for reservoir design and management is addressed in the first section. Some insights into time series analysis and the use of hydrological forecasts in improving reservoir performance are discussed in the second part of this section. Four contributions are provided in the second section in order to illustrate possible ways of addressing the requirements of sustainability in reservoir analysis. In the first contribution a new method for designing sustainable reservoirs, based on the De Novo programming approach, is presented as an idea for replacing the optimization of a given reservoir with the design of an optimal reservoir. Reservoir storage reallocation and reassessment of reservoir operational rules are considered to be the two main problems related to existing reservoirs to be addressed within the framework of sustainability. The second contribution provides a method for reassessment of existing reservoirs, which is based on the combined use of simulation and optimization. The main objective of the approach is to determine: (a) the active reservoir storage requirements based on the current demand; and (b) the best management strategy for the reservoir under consideration. The third contribution presents the cost and benefit allocation methodology for redevelopment of reservoirs. The methodology has been illustrated with two case studies: (a) the addition of new water users to an existing water supply system, and (b) the addition of new water users to a

system with additional reservoirs. The fourth contribution provides an innovative procedure developed to guide and lead the reservoir planning process based on the least marginal environmental impact (LMEI) rule. The LMEI rule is used to decide the size of reservoir only to the extent that the extra unit increase of dam height has the least negative environmental impact solution among all the economically feasible alternative means (reservoir or non-reservoir). The chapter ends with a conclusions section.

Methods presented here are not necessarily those recommended but rather serve as examples that attempt to relate reservoir planning and management with the principles of sustainable development. Other innovative ideas are being explored and will appear in the near future. One area of particular potential includes methods based on the use of fuzzy sets (e.g. Kojiri & Sakakima, 1993; Kojiri, 1995; Bender & Simonovic, 1996; Despic & Simonovic, 1997).

#### **4.1.2 Dimensions of reservoir analyses**

Large reservoirs are used to help development and management of natural resources so as to sustain the economic growth of a region and improve the overall welfare of its citizens. Reservoirs contribute to increased crop production, more efficient water use, and energy availability. However, the growth of population has resulted in increases in demand and use of water resources. Reservoirs are the most important elements of complex water resource systems used to respond to increases in demand (Simonovic, 1992).

Reservoirs are used for spatial and temporal redistribution of water quantity and quality, and changing the water's ability to generate hydropower. The main characteristic of reservoirs is multipurpose use. By building a dam, the storage created may be used for flood control, water supply (municipal, industrial and agricultural), low flow augmentation, hydroelectric power generation, navigation and recreation.

There is no single type of reservoir analysis problem but a multitude of decision problems ranging from determining optimum reservoir storage capacity to selecting optimal reservoir operating policies. Different problem structures and conflicting reservoir purposes require a complex mathematical description. The decision variables, objective functions and constraints vary for different types of reservoir problems. Their correct formulation is required to address the trade-off between different water use purposes (hydroelectric power generation, municipal and industrial water supply, irrigation, etc.) and recreation or flood control.

Reservoir problems contain inherent uncertainty. The random nature of reservoir inflows and other related hydrological variables is the next important characteristic of reservoir analysis. The concept of reservoir reliability is

probably one of the most important aspects involved in making meaningful decisions regarding reservoir active storage and release policies.

**Reservoir analysis problem** In its simplest form the reservoir analysis problem can be stated as: How large does the reservoir storage need to be to provide for a given demand with an acceptable level of reliability? This problem is also known as the determination of reservoir storage capacity. This is one of the main activities within the reservoir design procedure.

Other variations of this problem are possible, such as determining a reservoir release for a given capacity. If the time interval is longer the problem is called long-term operations planning. This problem is solved during the project planning phase.

The same problem may be addressed within a considerably shorter time frame when the project operation is the main concern. In that case the problem is called real-time reservoir operations.

In all three cases the basic problem remains unaltered. The relationship between inflow characteristics, reservoir storage capacity, reservoir release and reliability must be found.

**Reservoir purposes** Generally, in large multipurpose projects, the total reservoir storage is divided into three principal segments: (a) the flood control storage; (b) the active storage; and (c) the dead storage. The flood control storage capacity is used to reduce flood peaks and minimize potential downstream damage. The active storage is used to regulate streamflow and provide water supply for various purposes. The active storage capacity is the principal source of water for municipal, industrial and irrigation water supply. It also provides water for hydroelectric power generation, low flow augmentation, navigation and recreation. The dead storage capacity is used for sediment control, and, in some cases to increase the elevation of the active storage.

**Tools for sustainable reservoir analysis** The specific character of sustainable reservoir analysis calls for new tools. Occasionally they are only new in that they are actually being put into practice (optimization of the operation of multipurpose reservoir systems). In other cases they are new in that they implement techniques that are well established in the literature but have not yet been fully utilized (expert systems for monitoring, design, and operation of reservoir systems). Often they are new in that they are modified to address new problems arising from the application of sustainability principles to water management (reallocation of reservoir storage and reassessment of reservoir operating strategies). In still other situations they are new in that they introduce new ideas and implement new technologies for solving water management problems.

Meeting the growing diversifying demands of sustainable reservoir design and management requires use of very sophisticated, and yet flexible,

techniques capable of providing answers to many questions within the context identified earlier in this text. Four main categories of tools foreseen to be more actively used are:

- information systems (spatial and temporal data processing including statistics, database management tools and geographic information systems);
- systems analysis (simulation, optimization and multi-objective analysis);
- artificial intelligence (expert systems, neural networks, object oriented programming, fuzzy analysis, etc.); and
- technological tools (computer graphics, sound, animation, etc.).

All the tools to be used in sustainable reservoir analysis will be incorporated into the decision support framework (Simonovic, 1996).

## **4.2 HYDROLOGICAL INPUT FOR RESERVOIR DESIGN AND MANAGEMENT**

Hydrological information is the basis of reservoir design and management. This information includes time series of reservoir inflows, extreme discharges and hydrological forecasts. The measurement methods for collecting hydrometeorological data are rapidly progressing. Technology offered by radar, satellites, transmission networks is improving on a daily basis. So are the data processing and forecasting techniques. The general opinion is, however, that reservoir management is not taking advantage of the advanced technology for data collection and processing.

The following two sections of this chapter will discuss some important issues in time series analyses and hydrological forecasting for sustainable reservoir management.

### **4.2.1 Time series analysis of reservoir inflows**

The primary hypothesis commonly used in reservoir analyses is that the historical records of river runoff provide sufficient information to predict the most important characteristics of the reservoir inflow regime in the future. Interpretation of “the most important characteristics” and “the future” depends on the purposes of runoff control, the choice of time interval and storage requirements. In one case, “the most important characteristics” may be the mean and the variance of annual runoff series only, but in another case, they may include daily runoff regime characteristics over a long period.

If the reservoir storage is small compared to the annual inflow volume, the relatively short representative inflow series can be used for some reservoir